

# **TOWARD ROUTINE AUTONOMOUS MEASUREMENT AND INTERPRETATION OF OPTICAL VARIABILITY IN COASTAL WATERS**

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## **LONG-TERM GOALS**

Optical measurements can be used for describing oceanographic processes and for developing predictive models. However, a great deal of time and expertise is required for quality control, data management, and interpretation of results. The full potential of optical observation technology for oceanography will be realized only when appropriate measurements can be made routinely, with automatic generation of robust interpretations. Toward that end, our long-term goal is to broaden the utility of radiometric measurements (upwelling radiance and downwelling irradiance) so that turnkey systems can be developed for the generation of derived data, suitable for use by non-experts.

## **SCIENTIFIC OBJECTIVES**

This program of research is aimed at supporting the efforts of primary researchers to interpret water-leaving radiance as measured by radiometer buoys in coastal waters. Complementary measurements with profiling radiometers are also addressed. Efforts are directed toward: (1) characterizing instrument behavior in the field to define information potential and limitations of the measurements; (2) developing statistical methods for averaging data and rejecting spurious observations; (3) refining algorithms relating water-leaving radiance to properties of surface waters; and (4) supporting efforts to obtain novel information from radiometer buoys (e.g., ultraviolet attenuation and sea state).

## **APPROACH**

This work is closely coordinated with the NSERC/Satlantic Industrial Research Chair in Environmental Technology, a partnership between John Cullen (the Chair), Dalhousie University and Satlantic. The Research Chair facilitates collaborative research which is complemented by this ONR project, which funds additional technical support from Satlantic. Research is conducted with: Dr. William Miller (Dalhousie), who is studying the optical properties of coastal waters in relation to photochemical transformations of dissolved organic matter (field work is coordinated with that of Neil Blough, Univ. of Maryland); researchers from NOAA (including P.J. Stabenro and J. Napp), in projects to characterize bio-optical variability in the Bering Sea; and a team from the Maurice Lamontagne Institute, Fisheries and Oceans Canada (P. Larouche: Chief, Coastal Processes) looking at optical variability in estuarine and coastal waters of Canada. The approach is to pursue basic questions in bio-optics during collaborative research cruises and to use this ONR-sponsored effort to improve technologies for measurement, data

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analysis and interpretation. Integrated with this are the university-based research programs of Lewis and Cullen, directed toward improved interpretations of near-surface optical measurements.

## **WORK COMPLETED**

*Instrumentation and procedures for data reduction.* A 14-channel, UV-visible reflectance radiometer buoy was deployed during cruises off the east coast of the US, in the Bering Sea, and in the estuary and Gulf of St. Lawrence. A 13-channel, UV-visible profiling radiometer was used to estimate diffuse attenuation coefficients during the deployments (Miller et al. 1997; Cullen et al. 1998). Improved procedures for dark-current correction (Sildam et al. 1998) and for estimation of near-surface diffuse attenuation coefficients (Nieke et al. 1998) were developed. An airborne radiometer was used during operations in the Bering Sea (Davis et al. 1997), and procedures were developed for atmospheric and sun-glint corrections (Lazin et al. 1997). A radiometer buoy with k-chain (string of irradiance sensors to measure diffuse attenuation coefficients), was described, and data from a deployment during the summer of 1996, were presented (Lewis 1997). Anti-fouling treatments for optical instruments were evaluated (McLean et al. 1997).

*Analysis and interpretation of data.* Results from previous studies of upwelling radiance and downwelling irradiance in coastal waters were analyzed further and presented in a theoretical context. One result is a Semi-Analytical Model of Ocean Color and Attenuation as a Function of Trophic Status (SAMOCAFOTS; Ciotti et al. 1998), which parameterizes the relationship between blue:green upwelling radiance ratios (ocean color) and diffuse attenuation at 490 nm (e.g. Austin and Petzold 1981) as a function of the optical properties of phytoplankton and the concentration of colored dissolved organic matter (CDOM) and detritus, all of which are expressed as functions of chlorophyll concentration. Data from radiometer buoys were also used to describe interpretable features in the relationship between sun-induced chlorophyll fluorescence and irradiance (Cullen et al. 1997b). Data from our optical studies were used in several collaborative presentations and publications (Asanuma et al. 1997; Foley et al. 1997; Landry et al. 1997; Miller et al. 1997). The utility of optical observations for detecting and assessing algal blooms was discussed and results were presented in a paper for a special issue of Limnology and Oceanography (Cullen et al. 1997a).

*Ultraviolet radiation.* The move to UV wavelengths in our research program (Miller et al. 1997, 1998) opened new avenues for research. To chart a course, we developed and presented a theoretical construct for estimating diffuse attenuation of UV, photochemical fluxes and biological effects of UV, based on measurements of upwelling radiance in the visible (Cullen et al. 1997c). Complementary research on the biological effects of UV culminated in a full-spectral model of UV effects as influenced by ozone depletion and vertical mixing (Neale et al. 1997).

*Operational advances.* Improvement in instrument design, including the addition of UV wavelengths, as well as the development of better procedures for preliminary data analysis, have moved us closer to routine acquisition of derived products from measurements with radiometer buoys, airborne radiometers and profilers.

*Semi-analytical model.* Data from the field (Ciotti et al. 1997) and laboratory (Richardson et al. 1996) figured prominently in the development of SAMOCAFOTS, which describes the optical consequences of consistent changes of the size and pigmentation of phytoplankton assemblages with trophic status as reflected in chlorophyll concentration (see Yentsch and Phinney 1989). The model uses a set of assumptions about changes in phytoplankton community structure (cell size and pigmentation) and CDOM with chlorophyll concentration. This allows the development of regional algorithms and evaluation of deviations from typical Austin-Petzold type relationships between ocean color and diffuse attenuation. SAMOCAFOTS also generates pigment algorithms that show the influence of different assumptions about community structure of phytoplankton and covariance of CDOM with chlorophyll.

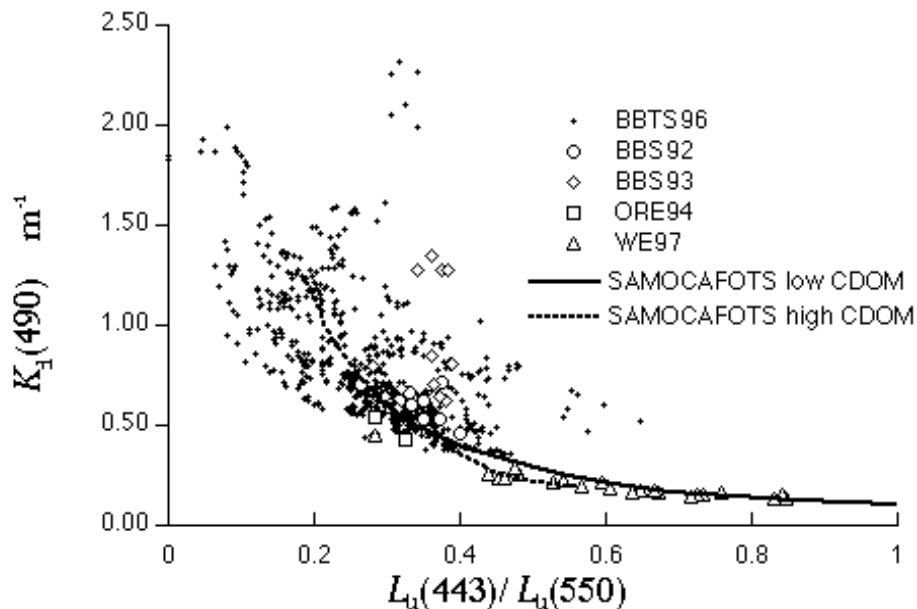


Figure 1. Symbols show the relationship between ocean color (blue:green radiance ratio,  $L_u(443)/L_u(550)$ ), as measured with radiometer buoys) and near-surface diffuse attenuation coefficient ( $K_d(490)$ ), measured with profiling radiometers [larger symbols] or a chain of irradiance sensors [dots]). Results are compared with a semi-analytical model (SAMOCAFOTS; Ciotti et al. 1998), parameterized for two relationships between chlorophyll concentration and the concentration of colored dissolved organic matter, CDOM. BB' stands for Bedford Basin (1992, 1993, 1996), ORE' is from off Oregon, and WE97' is from the Bering Sea.

*Ultraviolet radiation.* The procedure for estimating diffuse attenuation of UV, photochemical fluxes and biological effects of UV, based on measurements of upwelling radiance in the visible (Cullen et al. 1997c) has significant implications for synoptic assessment of photochemical processes in surface waters. A great deal of research will be needed before the utility of the approach can be fully assessed, but preliminary results are quite encouraging. By assessing the penetration of UV in surface waters, biological effects can be estimated. However, the calculation is difficult, and processes such as vertical mixing and repair processes must be considered. Our novel model of inhibition of photosynthesis by UV during vertical mixing (Neale et al. 1997) has the components necessary for application to a wide variety of biological and photochemical processes.

## IMPACT/APPLICATIONS

The research associated with this project, along with rapid advances by other workers, is moving us steadily toward achieving the stated goal of developing turnkey systems for measuring upwelling radiance and downwelling irradiance in surface waters and delivering derived data on water clarity and variability of important constituents of surface waters. Progress to date indicates that optical instruments will figure prominently in systems for routine environmental assessment and prediction in coastal waters as well as for rapid deployment and assessment in critical situations. Research on ultraviolet radiation in surface waters has revealed great potential for new applications in remote sensing and autonomous observation

systems. The link between ocean optics and UV research (photochemistry and photobiology) is likely to be strengthened greatly in the next few years.

## TRANSITIONS

Interest in this work is reflected in frequent inquiries from colleagues, requests to deliver talks, and invitations to participate in workshops. More directly, 10 radiometer-buoy systems have been sold for use in research. Research conducted under this program has led to significant advances in optical system design.

## RELATED PROJECTS

- 1) NSERC/Satlantic Industrial Research Chair: this partnership is the central source of support for instrumentation, field work, complementary lab studies, and university salaries. Funding for complementary projects, such as this ONR program, are highly leveraged by the research partnership.
- 2) W.L. Miller, Dalhousie (ONR): photochemical processes and optical properties of surface waters. We participate in the cruises (collaborating with N. Blough and T. Vodacek) share data, and collaborate on analysis. Miller focuses on photochemical processes, we emphasize optical properties.
- 3) NOAA-funded work in the Bering Sea (J. Cullen and R. Davis): optical observations from ships, moorings, drifters and aircraft are used to describe bio-optical variability in the Bering Sea as related to physical forcing (P.J. Stabeno, NOAA) in the context of fisheries oceanography (J. Napp, NOAA). Funding from ONR allows us to append research on UV and photochemistry.
- 4) Environment Canada (T. Clair): upwelling radiance and UV attenuation are measured in lakes and related to photochemical processes. The effort provides partial support for the development of relatively inexpensive, portable UV-vis radiometers.

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